Ocean Surface Wave Optical Roughness –
Innovative Measurement and Modeling

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LONG-TERM GOALS

We are part of a multi-institutional research team funded by the ONR-sponsored Radiance in a Dynamic Ocean (RaDyO) program. The primary research goals of the program are to (1) examine time-dependent oceanic radiance distribution in relation to dynamic surface boundary layer (SBL) processes; (2) construct a radiance-based SBL model; (3) validate the model with field observations; and (4) investigate the feasibility of inverting the model to yield SBL conditions. The goals of our team are to contribute innovative measurements, analyses and models of the sea surface roughness at length scales as small as a millimeter. This characterization includes microscale and whitecap breaking waves.

The members of the research team are
Michael Banner, School of Mathematics, UNSW, Sydney, Australia
Johannes Gemmrich, Physics and Astronomy, UVic, Victoria, Canada
Russel Morison, School of Mathematics, UNSW, Sydney, Australia
Howard Schultz, Computer Vision Laboratory, Computer Science Dept, U. Mass., Mass
Christopher Zappa, Lamont Doherty Earth Observatory, Palisades, NY

OBJECTIVES

Nonlinear interfacial roughness elements - sharp crested waves, breaking waves as well as the foam, subsurface bubbles and spray they produce, contribute substantially to the distortion of the optical transmission through the air-sea interface. These common surface roughness features occur on a wide range of length scales, from the dominant sea state down to capillary waves. Wave breaking signatures range from large whitecaps with their residual passive foam, down to the ubiquitous centimeter scale microscale breakers that do not entrain air. There is substantial complexity in the local wind-driven sea surface roughness microstructure, as is evident in the close range image shown in Figure 1. Traditional descriptors of sea surface roughness are scale-integrated statistical properties, such as significant wave height, mean squared slope (e.g. Cox and Munk, 1954) and breaking probability (e.g. Holthuijsen and Herbers, 1986). Subsequently, spectral characterisations of wave height, slope and curvature have been measured, providing a scale resolution into Fourier modes for these geometrical sea roughness parameters. More recently, measurements of whitecap crest length spectral density (e.g. Phillips et al,

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2001, Gemmrich et al., 2008) and microscale breaker crest length spectral density (e.g. Jessup and Phadnis, 2005) have been reported.

Our effort seeks to provide a more comprehensive description of the physical and optical roughness of the sea surface. We will achieve this by implementing a comprehensive sea surface roughness observational 'module' within the RADYO field program to provide optimal coverage of the fundamental optical distortion processes associated with the air-sea interface. Within our innovative complementary data gathering, analysis and modeling effort, we will pursue both spectral and phase-resolved perspectives. These will contribute directly towards refining the representation of surface wave distortion in present air-sea interfacial optical transmission models.

APPROACH

We build substantially on our accumulated expertise in sea surface processes and air-sea interaction. We are working within the larger team (listed above) measuring and characterizing the surface roughness. The group plans to contribute the following components to the primary sea surface roughness data gathering effort in RaDyO:

- polarization camera measurements of the sea surface slope topography, down to capillary wave scales, of an approximately 1m x 1m patch of the sea surface (see Figure 1), captured at video rates. [Schultz]
- co-located and synchronous orthogonal 75 Hz linear scanning laser altimeter data to provide spatio-temporal properties of the wave height field (resolved to O(0.5m) wavelengths) [Banner, Morison]
- high resolution video imagery to record whitecap data, from two cameras, close range and broad field [Gemmrich]
- fast response, infrared imagery to quantify properties of the microscale breakers, and surface layer kinematics and vorticity [Zappa]
- sonic anemometer to characterize the near-surface wind speed and wind stress [Zappa]

Our envisaged data analysis effort will include: detailed analyses of the slope field topography; laser altimeter wave height and large scale wave slope data; statistical distributions of whitecap crest length density in different scale bands of propagation speed and similarly for the microscale breakers, as functions of the wind speed/stress and the underlying dominant sea state. Our contributions to the modeling effort will focus on using RaDyO data to refine the sea surface roughness transfer function. This comprises the representation of nonlinearity and breaking surface wave effects including bubbles, passive foam, active whitecap cover and spray, as well as microscale breakers.

WORK COMPLETED

Our effort in FY08 has comprised (i) detailed planning and execution of the suite of sea surface roughness measurements conducted during the Scripps Institution of Oceanography (SIO) Pier Experiment from January 6-28, 2008 (ii) instrumentation validation, refinements and the necessary logistics for the RaDyO field experiment in the Santa Barbara channel during September 5-27, 2008.

In the field experiments, we have responsibility for two-axis scanning lidar wave height data from FLIP, single axis scanning lidar data from the Kilo Moana and the provision of internet communication between these two vessels. During FY08, we also refined our data gathering hardware systems and protocols and continued work on analysis techniques for characterizing the various roughness features.

We carried out processing and validation of our scanning lidar data from each of the 2008 field experiments. Two scanning lidars, configured to operate in quadrature, were deployed on FLIP to measure the large scale wave geometry (height and slope components). These measurements were collocated with our partner investigators' high resolution polarimeteric, infrared and optical imaging systems collecting the surface roughness data. We also progressed with our effort to develop a robust 'individual wave' decomposition capability so that local physical roughness elements can be detected and characterized along with their space-time phasing. This seeks to overcome the classical Fourier spectrum issue of bound versus free wave contributions in assessing true physical sea surface roughness.

Of major significance to our group's effort was Schultz's successful DURIP application to build a full polarization camera for use in RaDyO. Further details on progress with this development are given in the companion ONR RaDyO Annual Report by Schultz.

RESULTS

Figure 1 below shows the instrumentation deployed in the field testing phase. Banner/Morison deployed two orthogonal line scanning lidars, synchronized for zero crosstalk. The lidars were positioned on the boom so that their intersection point was within the common footprint of the polarimetric (Schultz), infrared (Zappa) and visible (Gemmrich) imagery cameras which were measuring small-scale surface roughness features and breaking waves.

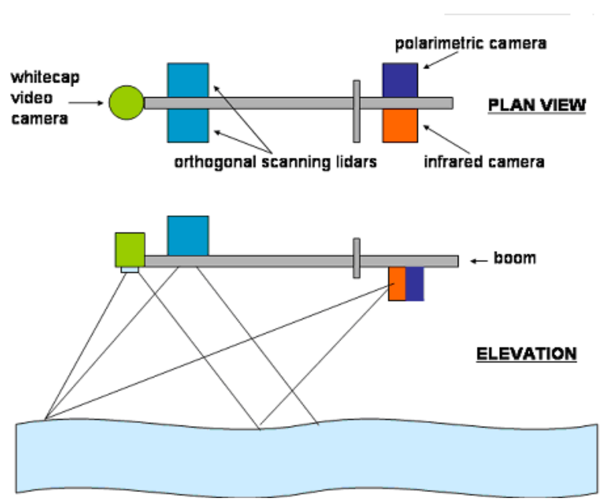

Figure 1. The left panel shows the instrumentation test set-up from the end of the Scripps Pier. The right panel shows a schematic of instrumentation packages deployed. The end of the boom was about 8m above the mean water level. The approximate field of view of the various instruments is shown. Another wide angle whitecap video camera was mounted well above the boom.

Zappa deployed his infrared/visible camera system (with blackbody target, a blackbody controller and a laser altimeter). He also deployed his environmental monitoring system (sonic anemometer, a Licor water vapor sensor, a Vaisala RH/T/P probe, a motion package, a pyranometer and a pyrgeometer). Gemmrich deployed 2 video visible imagery cameras. One camera was mounted on the main boom next to our other instrumentation packages. The second camera was mounted higher up to provide a wider perspective on larger scale breaking events. Schultz deployed an instrument package located on the boom that includes a polarimetric camera imaging the very small-scale waves. The individual data acquisition systems were synchronized to GPS accuracy which allowed the various data sets to be interrelated to within 0.1 seconds.

(ii) FLIP scanning lidar wave topography

Our scanning lidars were field-deployed from FLIP and the Kilo Moana during the first intensive observational experiment during September 2008 in the Santa Barbara channel. A wide range of conditions prevailed where the wind speed U_{10} ranged from light and variable, up to 25 knots. Figure 2 below shows typical scanning lidar data measured during reasonably strong wind forcing conditions, where the increase in specular surface facets provide more comprehensive off-nadir lidar returns than at lower wind speeds. The lidar was deployed from a boom at a height of ~8.5 m above the mean sea level. The lidar sensing spot on the sea surface had a diameter of ~0.15m, making an altimetric height determination every 0.5^o at a scan rate of 75 Hz.

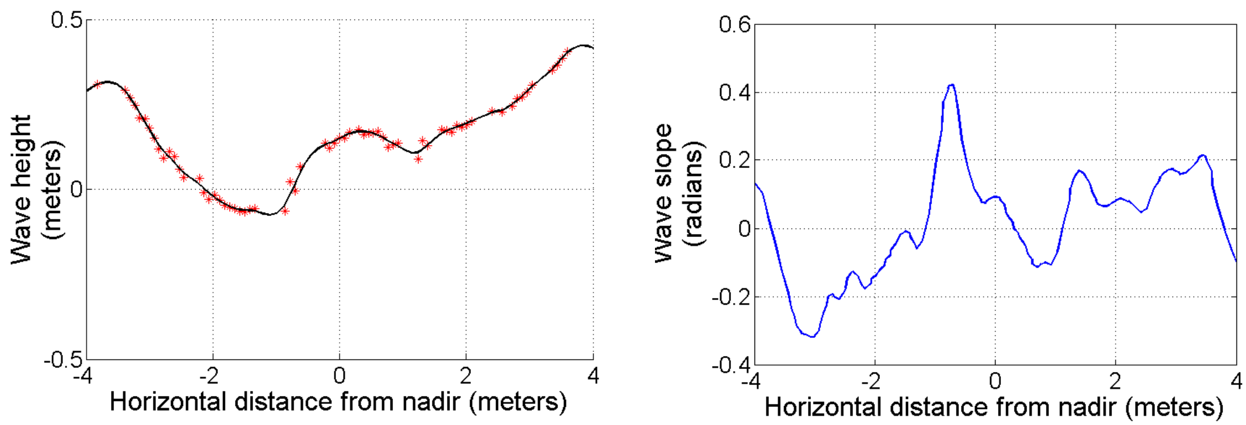

Figure 2. Example of the measured wave height and slope distribution in the wind direction from the new starboard boom on FLIP, using a scanning lidar. The red asterisks indicate the lidar data and the black line is the smoothed profile. The wave slope was derived from the smoothed wave height profile. The data was taken in approx. 15 knot winds in the Santa Barbara channel on 23 September, 2008.

The lidars operated continuously throughout the field experiments. As anticipated, the horizontal extent of the lidar return increased as the wind strengthened, because of the greater number of scatterers that provide the specular return facets for the lidar to make its time-of-flight measurement. Our experience confirmed that this method provides useful data on the height and.
local directional slope of the dominant waves. This information characterizes the background environment experienced by the short wind waves (the sea surface microstructure roughness). This information also allows accurate phasing of the polarimetric camera imagery of the sea surface microstructure with respect to the underlying dominant wind waves.

IMPACT/APPLICATIONS

This effort will provide a far more detailed characterization of the wind driven air-sea interface, including wave breaking (whitecaps and microscale breaking). This is needed to provide more complete parameterizations of these processes, which will improve the accuracy of ocean optical radiative transfer models and trans-interfacial image reconstruction techniques.

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